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Analysis of some elements of forest production in the Chic-Chocs Management Unit (western section)

Richard Zarnovican

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RÉSUMÉ

À partir de données sur la croissance des arbres dominants (Sab, Epb, Boj) de la partie occidentale de l'unité de gestion des Chic-Chocs, quelques aspects de la production en volume ont été analysés.

La comparaison des rendements du sapin baumier (*Abies balsamea* (L.) Mill) de cinq régions de croissance démontre que les régions appelées "Ia, Ib, IIa et IIb" ont un accroissement annuel en volume semblable, malgré les différences altitudinales qui les séparent. Cependant, ce même accroissement est nettement plus faible pour la région III, qui se situe à plus de 600 m d'altitude.

Le regroupement de 67 stations d'étude d'après l'accroissement annuel en volume a permis d'établir 9 groupes des stations. Les quatres premiers groupes de stations représentant le sapin baumier, sont statistiquement différents d'après le rendement en volume, en couvrant l'amplitude du plus grand accroissement au plus faible. Le groupe 5 reflète le rendement de l'épinette blanche (*Picea glauca* (Moench) Voss) et le groupe 6, le rendement du bouleau jaune (*Betula alleghaniensis* Britton). Les six premiers groupes sont

ABSTRACT

An analysis was carried out on some aspects of yield based on data on growth of dominant trees (balsam fir, white spruce, yellow birch) from the western section of the Chic-Chocs Management Unit.

Comparison of balsam fir (*Abies balsamea* (L.) Mill.) yields in five growth regions shows that the regions termed "Ia, Ib, IIa, and IIb" have similar annual volume increments in spite of their differences in elevation. This same increment is distinctly smaller in region III, which is located above 600 m of elevation.

By grouping 67 research plots according to annual volume increment, nine plot groups were established. The first four plot groups, representing balsam fir, are statistically different in terms of volume yields covering the range from the greatest increment to the smallest. Group 5 reflects the yield of white spruce (*Picea glauca* (Moench) Voss), and Group 6 the yield of yellow birch (*Betula alleghaniensis* Britton). The first six groups are located at elevations below 600 m. Finally, groups 7, 8, and 9 express the yields of balsam fir and white spruce at elevations above 600 m.

situés à des altitudes inférieures à 600 m. Enfin, les groupes 7, 8 et 9 expriment le rendement du sapin baumier et de l'épinette blanche pour les altitudes supérieures à 600 m.

Finalement, l'examen des relations entre les principales grandeurs dendrométriques de 9 groupes de stations complète le présent rapport.

The study of the relationships among the main growth characteristics of nine groups of stands completes the present report.

THE PROBLEM AND PURPOSE OF THE STUDY

Rational forest management to produce wood in quantity and quality calls for detailed knowledge of the production capacities of trees and stands. In Quebec, this capacity is evaluated on the basis of the site index - the height at a given age (Vézina and Linteau 1968; Bolghari 1977; Boudoux 1978), or the forest's flora (Lafond 1967), or the volume increment (absolute and relative: ITC, 1967; Majcen 1979)[1]. The advantages offered by these various methods largely depends on their use, the accuracy required, and the goal being sought. However, it must be understood that site and flora indices are no more than indirect approximations of productivity and are also involved in the testing of a number of assumptions. In a recent investigation (Zarnovican 1980)[2], I showed that Linteau's (1957) site indices, based on overall height at age 50, went against most hypotheses when they were applied to fir stands in the wooded massif of Lake Joffre. The same finding was made by the Chic-Chocs management unit team when they set out to evaluate site productivity on the exclusive basis of site indices (Tourigny personal communication).

The evaluation of productivity based on absolute or relative volume growth represents a step forward and a distinct improvement in our understanding of the complex question posed by forest productivity. Methods based on observation of volume increment must be used with discrimination, taking into account the productivity variations in terms of the timber stand's particular characteristics (endogenous factors) in relation to those due to the different biophysical variables (exogenous factors).

The present report analyzes the different growth data, together with the interrelations among them, in order to

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[1] Majcen, Z. 1979. Relations entre la végétation, les caractères d'habitat et le rendement dans la station forestière d'Argenteuil, Quebec (Relationships between vegetation, habitat character and yield in the forest stand of Argenteuil, Quebec). Doc. Thesis Univ. Laval. Fac. For. Geod., Laval Univ., Quebec City, 290 p. (Rapport Int. N° 193, Qué. Minist. Terres & For.).

[2] Zarnovican, R. 1980. Indices de fertilité et la production dans les sapinières. Pages 3-11 in Aménagement forestier: utilité et utilisation des indices de fertilité au Québec. Unpublished report, LFRC, Sainte-Foy, Québec, 3-11.

establish quantitative criteria suited for the classification of stands, thus giving the users (Chic-Chocs Management Unit team) an initial assessment of yield. My report follows the study by Gerardin et al. (1984)[3] on biophysical factors.

METHODOLOGY

Growth data were taken from sample plots identified during 1978 and 1979 summer projects that were concentrated around Lake Joffre, and sample plots identified in 1984 in the west of the Management Unit's territory. In each plot, 3 to 5 trees were chosen that did not show any visible defects in the crown or trunk and whose dbh was closest to the 95th percentile on the cumulative curve of the total stems on the plot. A complete stem analysis was carried out on selected trees. Stem analysis is a technique to study tree development and to reconstruct growth phases accurately and in a chronological sequence.

With this observation method, we established the tree's main dimensions: age, diameter, height and volume, as well as the respective increments. Based on these data, it was possible to establish the main relationships (allometric and temporal), and to identify periods of insect epidemics.

Stem analysis was carried out at the Laurentian Forestry Centre (LFC) using a tree rings measuring machine. The calculations involved in classification, increment rates, time of passage, and regression analysis were done at LFC using programs available on the PDP-11/44 computer.

The main growth variables reflect the development of the mean stem, not the development of a mean stand.

DEFINITIONS

The increment of a tree characteristic is its increase over units of time. We can speak of current annual increment, increment per year, or the periodic mean increment corresponding to the mean yearly increase in a variable for a given period. The increment can be absolute,

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[3] Gerardin, V.; Bérubé, D.; Ducruc, J.-P. 1984. Cadre écologique de référence de l'unité de gestion des Chic-Chocs (partie occidentale): Carte des topo-systèmes et des régions de croissance. Contributions de la division des inventaires écologiques, No. 12, 23 p.

in m^3/ha/yr, or relative, expressed as a percentage of the corresponding production. In this report, production is, unless otherwise indicated, volume of timber inside bark; the definition of the volume is always assumed to be completely fixed.

SYMBOLS

The customary symbols are used to identify tree measurements: v = volume; d = diameter at breast height of dbh; i = current annual increament; p = increment rate; h = height; t = time of passage; e = expected error at the threshold of a given probability; N = number of observations; n = the number of rings in the last radial cm.

FORMULAE

Mean periodic increment over 2 and 5 years is used to estimate current annual increment. The calculation is made using linear interpopulation, thus:

$$i = \frac{v(t_2) - v(t_1)}{t_2 - t_1}$$

In mathematical terms, this estimate is valid for periods of 2 and 5 years in phases of full growth and afterwards, since skewing is less than 0.01 percent (Zarnovican 1981).

The Pressler formula, was used for increment rates

$$p = \frac{200}{n} \cdot \frac{v(t_2) - v(t_1)}{v(t_2) + v(t_1)}$$

in preference to the compound rate formula, also known as the Leibniz formula,

$$p = 100 \left\{ [(v(t_2) \; / \; v(t_1)]^{1/n} - 1 \right\}$$

since this introduces considerably more skewing.

Time of passage, which is the number of years for which d increases by 2 cm or one class, has been established on the basis of diameter growth by the following formula

$$n = 2/i_d$$

It is assumed that the mean width of a ring is equal to 1/n, and thus that i_d is equal to 2/n.

Finally, expected error at the 95 percent threshold, using the following formula

$$e_{0.05} = t_{0.05}[v_x/(N-1)^{1/2}]$$

$t_{0.05}$ is the value of the Student test adjusted according to N-1 degrees of freedom; v_x is the coefficient of variation. The expected error allows us to measure the differences among the mensuration variables, statistically at least, stipulating that the true value in 95 percent of cases falls within a determined range.

DATA PREPARATION

Based on growth data, it was possible to establish that, during certain periods, insects affect the development of a tree and that plot quality was entirely obscured by this exogenous factor. Therefore, these growth data could be eliminated and only those data, that could reasonably be considered as resulting from the fertility of the site, could be used.

At a second stage, growth data was eliminated for the period when the diameter of the tree was less than 9 cm. We did this in order to consider only data on merchantable volume according to the norms of the Quebec Department of Energy and Resources to ensure that the juvenile phase in diameter and volume growth had been completed. The estimate of i by MPG (Mean periodic growth) in different growth variables satisfied the accuracy criteria.

HYPOTHESES AND LIMITATIONS

The growth data were taken from stem analysis of dominant trees according to their present position in the stand. On the basis of these data, it was assumed that these trees have also been dominant in the past.

This hypothesis has as its base the data for the distribution of the number of stems in fir stands, in which diametral structure changes with time from leftward and leptokurtical asymmetry to a normal distribution (Zarnovican 1983), and which also verify the stability of hierarchies in pure, uniform stands (Delvaux 1981). The results of our work are limited to dominant trees layer. In addition to being restricted in space, my results are also limited in time. According to Smelko (1976), stem-analysis data do not allow for prediction of future growth with acceptable accuracy beyond a 30-year period.

RESULTS AND DISCUSSION

Gerardin et al. (1984)[3] established a biophysical frame of reference for forest development in the western portion of the management unit. They defined the growth regions on the basis of an empirical analysis of elevation data, asserting that the strong presence of this factor in the region has a direct bearing on growth conditions and thus on the forest's productivity. In all, they identified five growth regions and associated these with the altitudinal sections of 150 m, characterized in terms of mean annual temperature and total yearly precipitation.

Analysis of tree growth data focused at an initial stage on the grouping of plots by growth region in order to check the hypotheses of Gerardin et al. (1984)[3] on the discriminant power these spatial units have on current annual volume increment. The main growth characteristics represent to the development of mean tree, not to the development of a mean stand (Table 1). The graphic expression of the relationship between current annual volume increase of trees and dbh for five growth regions is found in Figure 1. Looking at these data, one notes that:

- The number of observations vary from region to region;
- region Ia is distinctly undersampled;
- growth regions Ia, Ib, IIa, and IIb are similar in terms of volume productivity for balsam fir;
- region III is different from the others in terms of volume yield;
- we cannot infer a discriminant power in the growth regions on forest productivity.

The difficulty of separating the productivity classes using the growth regions prompted us, at a second stage, to group the plots, not by growth region, but by yield.

Using a classification algorithm, we separated 67 plots into 9 different groups. The first four groups are made up of plots dominated by balsam fir. The main mensuration variables that characterize the development of balsam fir according to its dbh appear in Table 2, and are accompanied by some biophysical characteristics of these groups in Table 3.

Group 5 is made up of plots for which we have data on white spruce growth. The main tree measurements of the group are in Table 4, and the biophysical characteristics in Table 5.

Group 6 is made up of a single plot, as are groups 7, 8, and 9. Group 6 represents the yield and growth conditions of yellow birch (see Tables 6 and 7).

Groups 7, 8, and 9 come from elevations above 600 m. The data on growth and yield have been grouped for white spruce and balsam fir, and these appear in Table 8. Table 9 summarizes the biophysical characteristics of the three plots.

Figure 2 illustrates productivity as reflected in annual volume increment and dbh for 9 groups of plots. Figure 2 also shows that annual volume increment i_v augments with a growing diameter; the relation between i_v and d is not a linear one; balsam fir and white spruce show a proportional i_v increase for the same diameter within the plot group; yellow birch shows an i_v increase in relation to d that differs from the resinous; the white spruce group productivity is comparable to the best balsam fir yield; groups 4, 8, and 9 are the least productive.

The classification algorithm made it possible, on the one hand, to individualize the plot group by variety and, on the other hand, to reduce the variance of different tree characteristics and, in particular, annual volume increment.

For example, despite a resemblance in biophysical data (elevation around 375 m, slopes from gentle to moderate, soil drainage from good to moderately good, with the surface layer made up essentially of saprolite, or disintegrated rock with a core of stone on fine-grained schistose sandstone), the first four groups of stands still cover the range of volume increments according to diameter.

To check the differences among the four groups based on volume increment according to diameter, I have given the respective yield data in Figure 3, adding the curves that show the interval of expected error at the 95 percent threshold. The result indicates that the four groups differ from one another statistically.

In the absence of relationships between volume yields and available biophysical variables for the stands of the first four groups, we will make a more detailed examination of some data on stocking of the stands and the growing space per tree in the first four groups (Table 10).

This table shows that: the stocking is appreciably the same for the four plot groups; the average area per tree is greater for the plots of Group 1 and decreases for the following groups, reaching its minimum for Group 4. The same remark applies to the average stand basal area.

There are several possible reasons to explain the differences in yield judged by diameter for the first four plot groups. For example: the samplings of biophysical variables in the stands were not detailed enough to assess yields, and the effect of repeated insect outbreaks caused continuous stress on the growth of young stands which could have gone undetected in stem analysis.

ANALYSIS OF SOME MEASUREMENTS FROM THE 9 MAIN GROUPS

In the light of the results obtained from the ordination of nine plot groups by productivity, and after comparing some available biophysical variables, I propose a more detailed analysis of some average tree characteristics and more particularly the relationships among them.

Rate of volume increment vs diameter

The relative expression of productivity is the rate of volume increment. As seen in Figure 4, the rates of increment in nine plot groups are expressed in terms of dbh. Figure 4 illustrates that: the rate of increment declines in terms of diameter; the relationship between the two measurements is curvilinear; the respective positions of the nine groups are the same as in Figure 2, and expected error is relatively small.

Diameter increment vs diameter

Diameter increment is a characteristic of the greatest importance in field work, for it is directly measurable on the core sample drawn out by Pressler's borer, and allows us to calculate, using the tariff differentiation formula, the current annual volume increment of trees and forest stands.

In Figure 5, the annual diameter increment is expressed in terms of the diameter for the nine plot groups. This is a diminishing relationship and it is more or less linear. From the respective positions of the groups, we note that diameter growth alone does not allow for an adequate assessment of volume yield, since groups 7, 8, and 9 have a diameter increment as large as groups 2, 3, 5, and 6. It is to be noted, however, that the respective position of the first four groups remains unchanged.

Annual volume increment vs annual diameter increment

The difficulty of estimating volume productivity by diameter increment can be seen in Figure 6, which shows the relationship between annual volume increment and annual increment in diameter. This figure indicates that there is no uniform relationship between volume increment and diameter increase. For example, in the case of groups 1, 2, 3, and 7, the volume increment rises with a gradual decrease in diameter increment; in Group 5, volume increment rises while increase in diameter remains virtually constant; and finally, in the case of groups 6 and 8, one can note a slow rise in volume increment coupled with a rapid fall in the increase in diameter.

Rate of volume increment vs rate of diameter increment

In contrast to the relationship between the respective increments, the relationship between the rate of volume increment and the rate of diameter increase (see Figure 7) is very close and more or less linear. However, the ordination of groups established on the basis of volume yield is not respected.

Total volume inside bark vs diameter

This is a basic relationship that is also known as the log rule. Figure 8 shows that the relationship between volume and diameter is close and curvilinear. According to the results obtained on expected error, we can establish the volume precisely enough on the basis of diameter. Figure 8 indicates that a single tariff is enough for estimating volume in the case of groups 1, 2, 3, 4, 5, and 6. However, the decrease in volume for the same diameter becomes more and more evident in groups 7, 8, and 9. As these groups (7, 8, and 9) come from elevations greater than 600 m, I suggest that separate log rules be devised for elevations greater than 750 m and elevations under 750 m.

Height vs diameter

The relationship between height and diameter is a guiding one in the use of log tariffs. The data on height and diameter are reported in Figure 9. This figure clearly confirms the need to have separate tariffs for the zones above and below 750 m on the one hand and, on the other, shows that Group 6, yellow birch, has a distinctly greater height for the same diameter in relation to the rest. Moreover, groups 1, 2, 3, 4, 5, and 7 show appreciably similar heights, given the same diameter, for balsam fir as for white spruce.

Volume increment vs volume

Rational forest development requires foresters to follow closely and regularly check on the production of wood, particularly the current annual increment. It is recognized, however, that direct measurement of this increment runs up against some considerable technical difficulties, and that, for the moment, satisfactory observation methods do not exist.

Knowing that the balsam fir stands show a naturally standard diametral structure makes it of interest to study the relationship between volume increment and the volume of the mean tree. If this relationship turned out to be linear, it would be possible to calculate the current annual volume increment of a stand on the basis of the annual volume increment of the average tree. This is the precise objective of the analysis of Figure 10, in which is reported the respective data for annual volume increment and the volume of the mean tree from 9 plot groups. The data indicate that there is a relationship between this increment and volume, and that the relationship is a linear one. Moreover, it can be seen in this figure that the ordination of stand groups is appreciably the same as for productivity. However, there is a notable difference between yellow birch and conifers.

Time of passage vs diameter

The method of tariff differences is based, depending on its formulation, either on annual increase in diameter or else on its reciprocal value, generally known as time of passage. This measurement expresses the number of years needed for the diameter to be enlarged by one diameter class. The respective data are reported in figure 11 and they indicate an ordination of plot groups contrary to the one established using diameter increase and diameter. In addition, one can also see that if the diameter increment generally decreases as the diameter itself grows, the time of passage, by contrast, generally increases as the diameter grows (see Figure 11).

TREE BARK FACTOR

To ensure continuity of work on assessment of forest productivity by management unit officers using the tariff differential method, I will now look at the final element, tree bark.

Up to now, I have discussed tree measurements inside bark. In field inventory, however, diameters are measured outside or inside bark, and for this reason I think it is necessary to study this factor more closely.

Let us consider a tree with a dbh and volume v that varies as functions of time t. At a given moment, its current volume increment is dv/dt, which can be expressed as:

$$\frac{dv}{dt} = \frac{dv}{dd} \cdot \frac{dd}{dt}$$

The first term of this product is given by the derivative of the log tariff at an entry v(d) that is applicable, at moment t, to a given growth zone:

$$\frac{dv}{dd} = v'(d)$$

The second term $\frac{dd}{dt}$ of the product is the current increase in diameter of the tree, outside or inside bark, at moment t. It can be evaluated by tree borings on the stand.

Diameter inside bark

This procedure has been followed up to now by the management unit and has been described in Zarnovican (1983). It is appropriate to remember that this procedure expresses current volume increment in its relative form, thus by the rate of volume increment, which is calculated using the following formula:

$$p_v(\%) = \frac{v'(d)}{v} \cdot \frac{dd}{dt} \cdot 100$$

Diameter outside bark

Let us suppose that the mean periodic increment i_d can be calculated based on the radial increment using the equation

$$\frac{dd}{dt} = \frac{2(r_2 - r_1)}{t_2 - t_1} \cdot k$$

where r_2 and r_1 are the radii at time t_2 and t_1, and k is the bark factor. If $r_2 - r_1$ equals f and $t_2 - t_1$ equals w, when we substitute in the proceeding formula, we obtain:

$$\frac{dv}{dt} = \frac{2k}{w} \cdot fv'(d)$$

It was established by analyzing data on the bark of 183 balsam fir and white spruce trees that the bark factor k is equal to 1.05235 with an expected error at the 95 percent threshold of 0.00642.

Finally, analysis of data on the rate of bark in total tree volume and diameter with bark enables us to establish that the relationship between these two values is a linear, diminishing one (see figure 12), and very close. Moreover with the expression

$$\% \text{ of bark in volume} = 14.35801 - 0.1439 \cdot d_{(o.b.)}$$

we can calculate the bark percentage with a relative error of 3.0 percent.

CONCLUSION

The forest is a complex natural process, hard to grasp and model. To be able to do so, one must have well-established experimental techniques and observe production over sufficiently long periods. On the basis of data from the analysis of 183 dominant stems from 67 stands in the western portion of the Chic-Chocs Management Unit, we have looked at the growth and development of mean individuals using some of their forest mensuration dimensions according to the dbh. In accordance with tradition, we have choosen the current annual volume increment of the average tree for measuring productivity and classifying the research plots. In the first stage, this index was used for comparing the biophysical units of Gerardin et al. (1984)[3].

The result of this comparison indicates that the units known as "growth regions" Ia, Ib, IIa, and IIb have similar annual volume increments in spite of the differences in elevation among them. The result also shows that this same increment is distinctly smaller for the altitudinal section above 750 m. This result led us to compare the annual volume increment of one stand with another and to group those stands with similar increments. Using this method, it was possible to individualize nine plot groups: four representing balsam fir at elevations under 600 m, one stand of white spruce, one stand of yellow birch, and three stands of balsam fir and white spruce combined at elevations above 600 m.

Groups 1, 2, 3, 4, and 5 are well sampled: in groups 6, 7, 8, and 9 further sampling is needed. Of the deciduous trees to be sampled are: yellow birch, sugar maple, poplar, and birch; and the coniferious trees, (balsam fir, white and black spruce, and larch) at elevations above 600 m. The first four plot groups, representing balsam fir, are statistically different in terms of their volume increments according to dbh covering the range from the highest increment to the lowest. However, the resemblance between the biophysical data from the stands of these four groups - elevation, drainage, slope, and exposure - prevents us, for the moment, from using these factors to explain the differences. In addition, analysis of available data on the stocking and growing space of the stands does not indicate that the differences are due to the particular diametral structure.

Considering these conditions, we can advance two hypotheses:

- sampling of biophysical variables is not detailed enough at plot level to be able to explain and distinguish the various levels of productivity;
- growth and development of balsam fir and white spruce stands are affected by spruce budworm outbreaks to the point where stress is not noticeable, even in stem analysis.

However, study of the data on yield and the allometric data (log tariff, height vs diameter) indicates that stands above 750 m elevation are less productive, that decline in productivity is gradual, and that it is necessary to devise log rules especially for this zone.

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APPENDIX 1

Table 1. Measurement characteristics of balsam fir by growth region

d cm	N	v dm³	e_v %	p_v %	e_{p_v} %	i_v dm³	e_{i_v}* %
			Growth region Ia				
10	2	39.25	267.6	14.93	26.8	5.85	241.3
12	4	55.77	51.5	12.96	19.6	7.07	32.4
14	4	85.91	38.3	9.50	35.4	7.92	10.8
16	6	125.22	19.5	6.39	12.9	7.89	8.7
18	2	150.46	104.7	5.82	35.9	8.76	140.4
			Growth region Ib				
10	15	39.09	9.0	9.63	14.2	3.71	14.3
12	43	57.84	5.6	7.80	10.1	4.39	9.5
14	43	87.75	4.9	6.95	8.0	6.07	9.0
16	36	126.67	5.5	5.88	8.2	7.39	9.3
18	21	172.81	6.9	5.48	21.1	9.18	16.5
20	9	216.65	12.3	4.56	20.6	9.90	25.8
22	7	297.50	11.6	3.51	23.9	10.42	26.6
24	6	350.30	23.0	4.70	72.2	15.21	44.4
			Growth region IIa				
10	15	37.63	7.9	12.63	10.5	4.72	10.5
12	49	55.83	5.2	10.69	7.1	5.78	5.3
14	62	83.27	4.3	8.79	5.7	7.16	4.9
16	66	121.97	3.6	7.10	6.7	8.44	5.3
18	53	168.75	3.5	5.85	6.4	9.72	5.2
20	31	219.89	5.0	5.01	6.5	10.86	5.0
22	10	284.67	9.4	4.89	16.1	13.65	9.5
24	4	332.18	23.6	4.00	34.5	13.07	14.6
			Growth region IIb				
10	6	31.02	33.0	14.27	20.6	4.35	29.7
12	9	57.55	19.9	10.59	26.9	5.69	14.3
14	13	86.09	11.9	8.34	19.7	6.86	11.7
16	12	133.52	12.4	5.85	20.5	7.53	13.4
18	9	202.83	14.6	4.91	25.3	9.50	10.7
20	8	249.81	15.8	4.05	22.5	9.83	16.1
22	7	303.70	18.9	4.01	27.2	11.82	20.5
24	7	379.85	17.2	3.39	11.3	12.88	20.3
			Growth region III				
10	8	26.72	14.0	11.11	16.6	2.92	12.1
12	17	44.50	11.4	8.97	7.6	3.91	7.6
14	17	69.50	12.3	6.88	10.3	4.61	6.1
16	7	85.31	19.1	5.26	21.3	4.40	19.3
18	2	110.98	136.1	5.63	4.2	6.25	140.3
20	3	152.82	34.3	4.60	49.8	6.95	16.3
22	2	195.51	54.6	3.45	180.0	6.73	125.8

*

d = diameter at height 1.3 m of tree inside bark (cm);
N = number of observations;
v = total tree volume inside bark;
p_v = rate of tree volume increment;
i_v = annual tree volume increment inside bark;
e = expected error on the 95 percent threshold.

Table 2. Main measurements for balsam fir by group of stands

d cm	N	i_d mm	e_{i_d} %	P_d %	e_{p_d} %	v dm^3	e_v %	i_v dm^3	e_{i_v} %	P_v %	e_{p_v} %	h m	e_h %	t* years
						Group 1								
10	7	5.3	15.9	5.02	15.0	37.9	13.4	5.6	11.6	14.8	12.0	8.9	13.3	3.9
12	20	5.3	9.0	4.39	9.4	54.5	9.4	6.6	6.3	12.4	7.2	9.3	6.4	3.9
14	26	4.9	5.7	3.51	5.5	84.1	7.3	8.4	5.5	10.1	5.2	10.8	4.7	4.2
16	18	5.0	7.5	3.11	8.1	120.7	7.4	10.7	5.6	9.0	5.8	12.0	5.4	4.1
18	13	4.8	26.0	2.69	26.3	167.0	9.8	13.2	12.0	8.0	16.4	13.4	7.1	4.5
						Group 2								
10	17	4.8	14.3	4.64	14.4	34.8	11.1	4.5	11.1	13.3	11.4	7.9	6.9	4.4
12	41	4.5	8.1	3.73	8.6	55.5	6.0	5.6	5.9	10.5	8.1	9.4	4.2	4.9
14	50	4.1	7.5	2.95	7.9	83.4	5.2	6.9	5.0	8.5	6.7	10.7	4.0	5.3
16	35	3.9	7.7	2.43	7.3	116.7	6.1	8.2	5.0	7.2	6.1	11.6	4.6	5.4
18	19	3.8	11.6	2.11	11.7	165.1	8.6	10.2	3.5	6.4	9.7	13.1	6.6	5.6
20	9	3.5	20.6	1.79	20.1	199.1	10.9	11.0	5.9	5.6	11.9	13.3	12.0	6.0
						Group 3								
10	8	3.8	13.7	3.63	15.5	37.0	17.4	3.9	14.5	10.8	15.2	8.2	9.9	5.4
12	22	3.3	9.7	2.70	10.8	58.3	8.6	4.5	8.3	8.0	10.0	9.3	5.1	6.3
14	27	2.8	7.3	2.01	7.2	86.2	5.7	5.4	6.0	6.3	4.2	11.2	4.2	7.3
16	25	2.6	8.0	1.61	8.5	126.7	6.4	6.5	6.2	5.2	7.7	12.7	4.1	8.1
18	11	2.4	8.8	1.31	10.2	186.5	11.2	8.0	6.3	4.4	8.3	14.3	5.7	8.6
						Group 4								
10	7	2.4	17.1	2.31	18.2	39.0	13.5	2.7	14.9	7.0	11.4	8.5	8.9	8.6
12	14	2.1	17.0	1.78	17.5	60.0	10.1	3.4	9.2	5.8	11.9	10.2	5.1	10.0
14	6	2.2	13.3	1.65	17.1	81.3	14.1	4.3	10.2	5.3	16.5	11.3	4.8	9.1

*

d = tree diameter at height 1.3 m inside bark;
N = number of observations;
i_d= annual tree diameter increment;
p_d= rate of tree diameter increment;
v = tree volume inside bark;
i_v= annual tree volume increment inside bark;
p_v= rate of tree volume increment;
h = tree height;
t = time of passage or number of rings in the 2-cm class;
e = expected error at the 95 percent threshold.

Table 3. Byophysical characteristics for four groups of balsam fir stands

Group 1

Elevation: av= 360 m, s.d.= 68 m; **Slope:** av= 4.6%, s.d.= 4.7%;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; **Growth region:**	Ia	Ib	IIa	IIb	III
(%)		40	33	-	7	-	-	7	13	(%)		7	20	73	-	-

Drainage (class):	1	2	3	4	5	; **Surface:**	lsg	lsg(R)	lsa(R)	2bg	1fo	lcg(R)
(%)		-	33	67	-	-	(%)	53	20	7	7	7	6

Group 2

Elevation: av= 397 m, s.d.= 79 m; **Slope:** av= 14.6%, s.d.= 11.7%;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; **Growth region:**	Ia	Ib	IIa	IIb	III
		8	38	4	-	8	17	13	4	8	(%)		-	29	58	13	-

Drainage (class):	1	2	3	4	5	; **Surface:**	lsg	lsg(R)	lsa(R)	2bg	1fo	lcg(R)	lgm
(%)		17	46	29	8	-	(%)	79	5	4	-	-	8	4

Group 3

Elevation: av= 377 m, s.d.= 59 m; **Slope:** av= 12.7%, s.d.= 12.5%;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; **Growth region:**	Ia	Ib	IIa	IIb	III
(%)		-	20	-	7	-	27	13	20	13	(%)		-	56	31	13	-

Drainage (class):	1	2	3	4	5	; **Surface:**	lsg	lsg(R)	lsa(R)	2bg	1fo	lcg(R)
(%)		6	31	56	7	-	(%)	100	-	-	-	-	-

Group 4

Elevation: av= 375 m, s.d.= 12 m; **Slope:** av= 9%, s.d.= 4.6%;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; **Growth region:**	Ia	Ib	IIa	IIb	III
		-	67	-	-	-	-	-	33	(%)		-	67	33	-	-

Drainage (class):	1	2	3	4	5	; **Surface:**	lsg	lsg(R)	lsa(R)	2bg	1fo	lcg(R)	lgm
(%)		-	67	33	-	-	(%)	100	-	-	-	-	-	-

Table 4. Main measurements for white spruce in Group 5

d cm	N	i_d mm	e_{i_d} %	p_d %	e_{p_d} %	v dm^3	e_v %	i_v dm^3	e_{i_v} %	p_v %	e_{p_v} %	h m	e_h %	t years
10	7	5.2	35.4	4.9	35.4	39.5	7.5	5.4	25.9	13.7	26.5	8.9	11.7	4.4
12	12	4.9	28.5	4.0	28.6	59.7	10.5	6.3	19.2	10.9	22.9	9.8	12.7	4.9
14	18	4.2	18.7	3.0	19.7	90.4	8.2	7.5	10.4	8.6	15.7	11.6	8.3	5.5
16	25	4.4	15.1	2.8	15.1	121.5	9.3	9.4	9.7	8.0	12.1	12.2	8.6	5.1
18	18	4.5	14.4	2.5	14.2	170.3	10.0	12.3	9.0	7.5	12.9	13.8	9.2	4.8
20	18	4.4	15.7	2.2	15.5	231.6	9.7	14.9	10.1	6.6	13.4	15.1	8.2	4.9
22	7	4.4	21.8	2.0	21.8	267.0	10.6	16.8	19.4	6.3	15.9	15.4	8.8	4.8

*
d = tree diameter at height 1.3 m inside bark;
N = number of observations;
i_d= annual tree diameter increment;
p_d= rate of tree diameter increment;
v = tree volume inside bark;
i_v= annual tree volume increment inside bark;
p_v= rate of tree volume increment;
h = tree height;
t = time of passage or number of rings in the 2-cm class;
e = expected error at the 95 percent threshold.

Table 5. Biophysical characteristics for stands in Group 5

Elevation: av= 358 m. s.d.= 66 m; Slope: av= 10%; s.d.= 9%;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; Growth region:	Ia	Ib	IIa	IIb	III
(%)		14	43	-	-	-	21	8	-	14	(%)	7	22	71	-	-

Drainage (class):	1	2	3	4	5	; Surface:	lsg	lsg(R)	lsa(R)	2bg	1fo	lcg(R)
(%)	7	43	36	14	-	(%)	79	7	-	-	-	14

Table 6. Main measurements for yellow birch in Group 6

d cm	N	i_d mm	e_{i_d} %	p_d %	e_{p_d} %	v dm^3	e_v %	i_v dm^3	e_{i_v} %	p_v %	e_{p_v} %	h m	e_h %	t* years
12	4	5.6	24.8	4.7	23.4	59.5	26.5	7.3	31.0	12.2	16.5	11.6	5.9	3.6
14	4	5.4	34.7	3.8	37.2	92.3	21.8	8.6	24.6	9.4	31.5	12.7	3.9	3.8
16	5	4.5	18.5	2.8	16.7	128.4	14.2	8.3	15.8	6.4	9.3	13.8	3.9	4.5
18	5	3.6	28.7	2.0	30.6	174.1	11.4	9.0	19.2	5.2	27.0	15.0	3.3	5.8
20	4	3.4	35.9	1.7	34.3	214.3	10.1	9.5	24.5	4.5	28.5	15.9	4.5	6.1

*

d = tree diameter at height 1.3 m inside bark;

N = number of observations;

i_d = annual tree diameter increment;

p_d = rate of tree diameter increment;

v = tree volume inside bark;

i_v = annual tree volume increment inside bark;

p_v = rate of tree volume increment;

h = tree height;

t = time of passage or number of rings in the 2-cm class;

e = expected error at the 95 percent threshold.

Table 7. Biophysical characteristics for stands in Group 6

Elevation: av= 330 m; s.d.= — m; Slope: av= 0%; s.d.= — %;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; Growth region:	Ia	Ib	IIa	IIb	III
(%)		100	-	-	-	-	-	-	-	(%)		-	100	-	-

Drainage (class):	1	2	3	4	5	; Surface:	lsg	lsg(R)	lsa(R)	2bg	lfo	lcg(R)
(%)		-	100	-	-	(%)	100	-	-	-	-	-

Table 8. Main measurements for the balsam fir and white spruce by group of stands

d	N	i_d	e_i	p_d	e_p	v	e_v	i_v	e_i	p_v	e_p	h	e_h	t
cm		mm	%	%	%	dm^3	%	dm^3	%	%	%	m	%	years
Group 7														
10	7	3.5	13.4	3.4	13.9	30.9	12.1	3.2	15.5	10.2	11.2	7.5	7.6	5.8
12	14	3.3	8.0	2.8	8.4	51.5	11.1	4.5	10.9	8.9	7.9	9.2	4.4	6.1
14	8	3.0	13.6	2.2	14.8	79.3	12.6	5.4	11.0	6.9	11.6	10.7	5.2	6.8
Group 8														
10	4	4.8	25.3	4.8	26.6	24.2	27.0	3.0	30.7	12.6	25.0	5.3	9.0	4.2
12	13	4.3	8.4	3.6	10.0	37.1	11.2	3.4	12.3	9.3	8.9	5.8	5.8	4.7
14	9	4.2	11.0	3.0	12.0	54.6	11.4	4.3	13.9	7.9	10.0	8.7	7.1	4.9
16	3	3.2	39.5	2.1	33.8	72.7	16.1	4.2	42.9	5.8	49.0	7.0	16.2	6.3
Group 9														
12	3	3.5	54.2	2.9	68.7	43.1	21.8	3.4	69.9	7.7	57.4	7.1	27.5	5.9
14	3	3.8	27.0	2.8	33.0	63.1	26.9	4.7	57.4	7.4	44.4	8.0	34.0	5.2
16	2	3.6	65.2	2.3	78.7	83.4	59.6	4.8	85.0	5.7	86.4	8.3	14.7	5.8
18	2	3.7	53.9	2.1	68.1	110.9	66.1	6.3	90.3	5.6	11.2	9.3	8.2	5.5

*

d = tree diameter at height 1.3 m inside bark;

N = number of observations;

i_d = annual tree diameter increment;

p_d = rate of tree diameter increment;

v_i = tree volume inside bark;

p_v = rate of tree volume increment;

h = tree height;

t = time of passage or number of rings in the 2-cm class;

e = expected error at the 95 percent threshold.

Table 9. Biophysical characteristics for groups of stands

Group 7

Elevation: av= 660 m; s.d.= — m; Slope: av= 10%; s.d.= — %;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; Growth region:	Ia	Ib	IIa	IIb	III
(%)	-	-	-	-	-	-	-	-	100	(%)	-	-	-	-	100

Drainage (class):	1	2	3	4	5	; Surface:	lsg	lsg(R)	lsa(R)	2bg	lfo	lcg(R)	lgm
(%)	-	100	-	-	-	(%)	-	-	-	-	-	-	100

Group 8

Elevation: av= 870 m; s.d.= — m; Slope: av= 7%; s.d.= — %;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; Growth region:	Ia	Ib	IIa	IIb	III
(%)	-	-	100	-	-	-	-	-	-	(%)	-	-	-	-	100

Drainage (class):	1	2	3	4	5	; Surface:	lsg	lsg(R)	lsa(R)	2bg	lfo	lcg(R)	lgm
(%)	-	100	-	-	-	(%)	-	-	-	-	-	-	100

Group 9

Elevation: av= 825 m; s.d.= — m; Slope: av= 10%; s.d.= — %;

Exposure:	nil	N	NE	E	SE	S	SW	W	NW	; Growth region:	Ia	Ib	IIa	IIb	III
(%)	-	-	-	100	-	-	-	-	-	(%)	-	-	-	-	100

Drainage (class):	1	2	3	4	5	; Surface:	lsg	lsg(R)	lsa(R)	2bg	lfo	lcg(R)	lgm
(%)	-	-	100	-	-	(%)	-	-	-	-	-	-	100

Table 10. Data on stocking and growing space for the plots of the first four groups

Group		1	2	3	4
Stocking (%)	mean	90.6	84.0	93.2	91.3
	s.d.	13.1	10.1	10.0	3.8
Growing space (m^2)	mean	4.84	3.73	2.59	1.51
	s.d.	1.20	2.03	1.44	0.66
Mean stand basal area (dm^3)	mean	2.39	1.92	1.48	0.92
	s.d.	0.68	0.74	0.54	0.31
Number of stands		7	19	16	3

APPENDIX 2

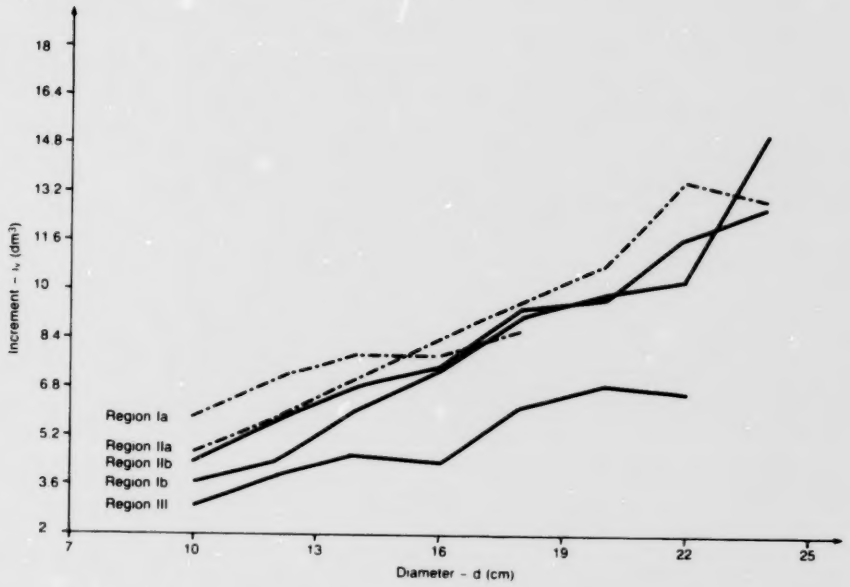

Figure 1. Tree annual volume increment (i.b.) in relation to dbh (i.b. for five growth regions.

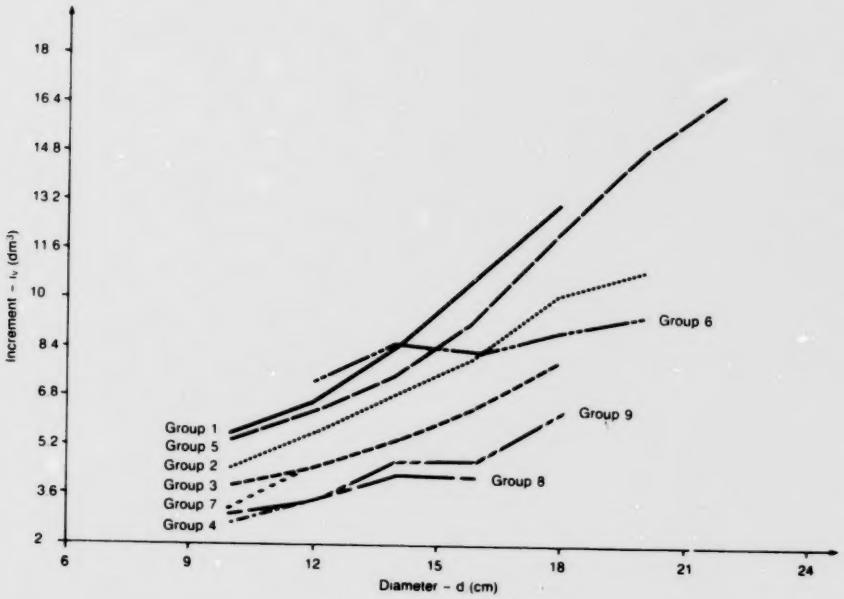

Figure 2. Tree annual volume increment (i.b.) in relation to dbh (i.b.) for nine groups of plots.

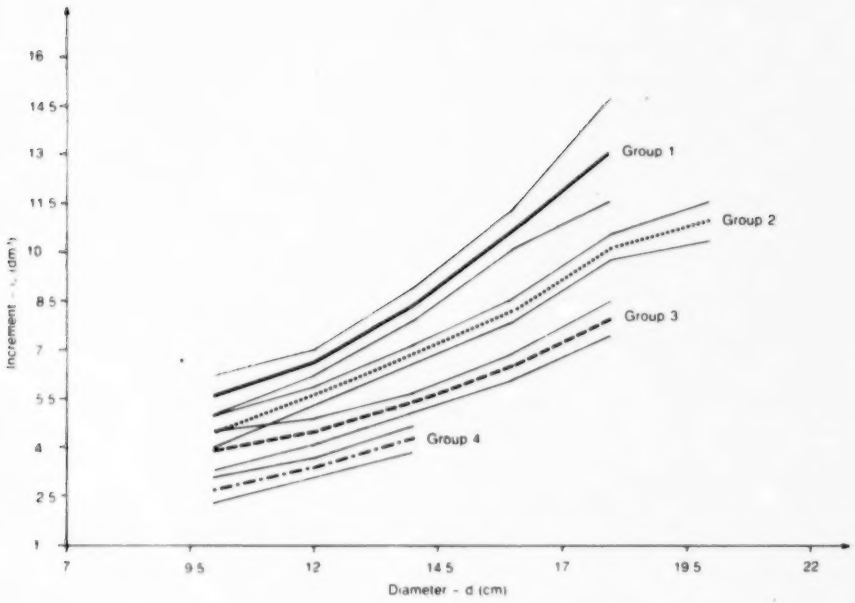

Figure 3. Tree annual volume increment (i.b.) in relation to dbh (i.b.) and the interval of expected error at the 95 percent threshold for balsam fir on the first four plot groups.

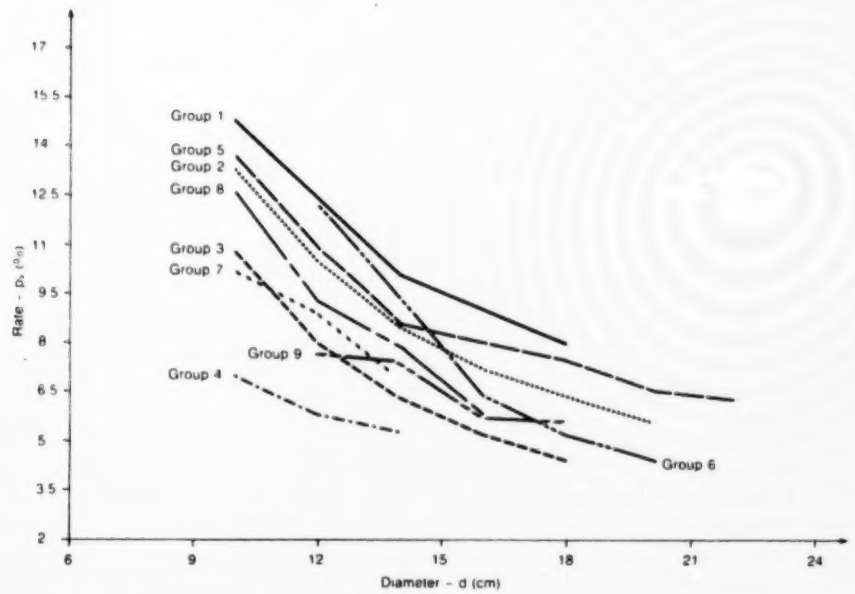

Figure 4. Rate of tree volume increment in relation to dbh (i.b.) for nine plot groups.

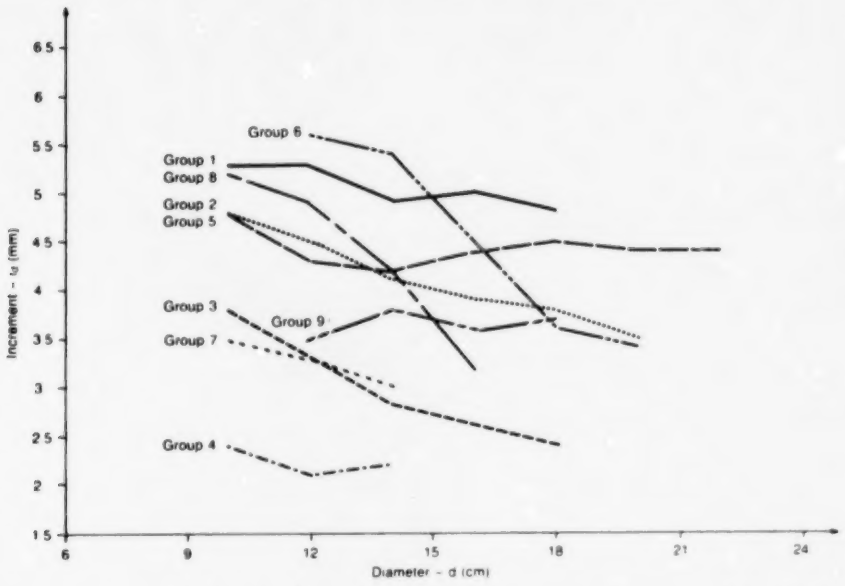

Figure 5. Tree annual diameter increment in relation to dbh (i.b.) for nine plot groups.

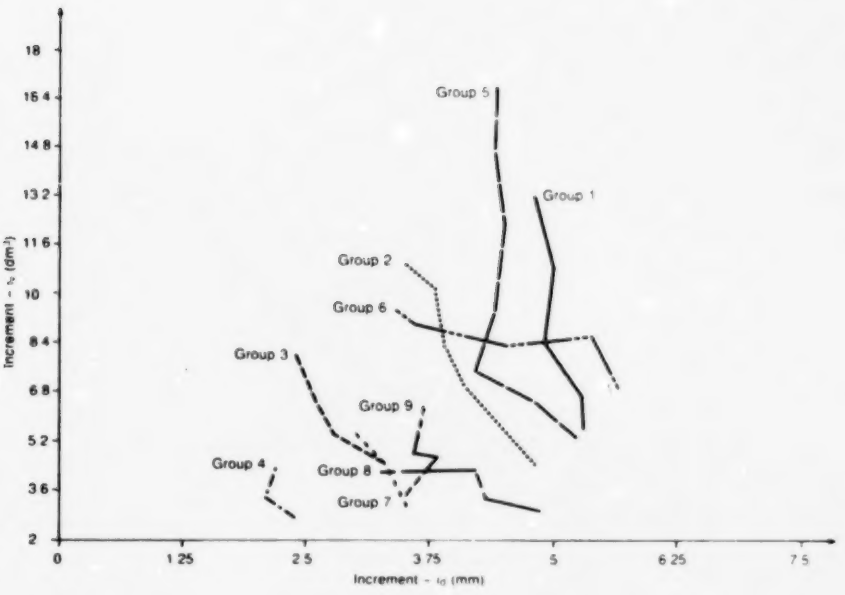

Figure 6. Tree annual volume increment (i.b.) in relation to annual diameter increment (i.b.) for nine groups of stands.

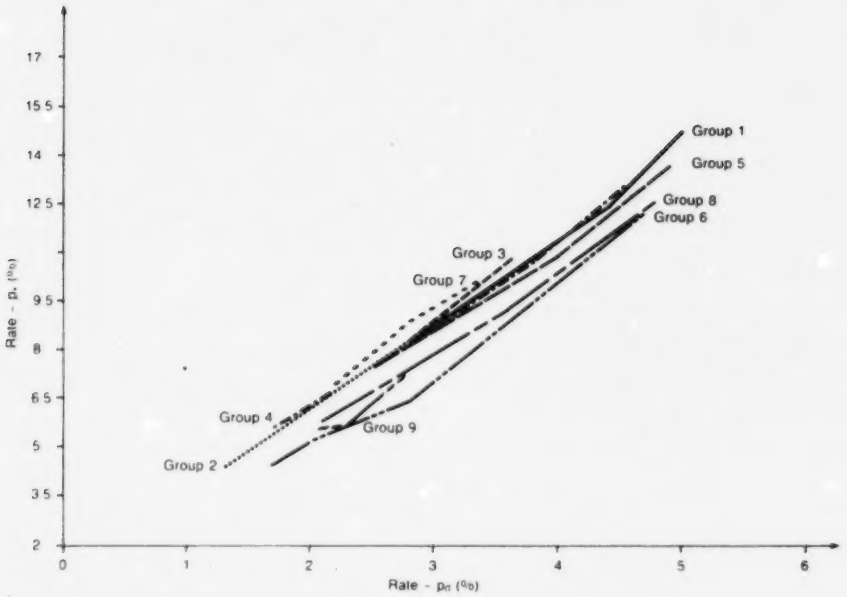

Figure 7. Tree volume increment percent in relation to diameter increment percent for nine groups of stands.

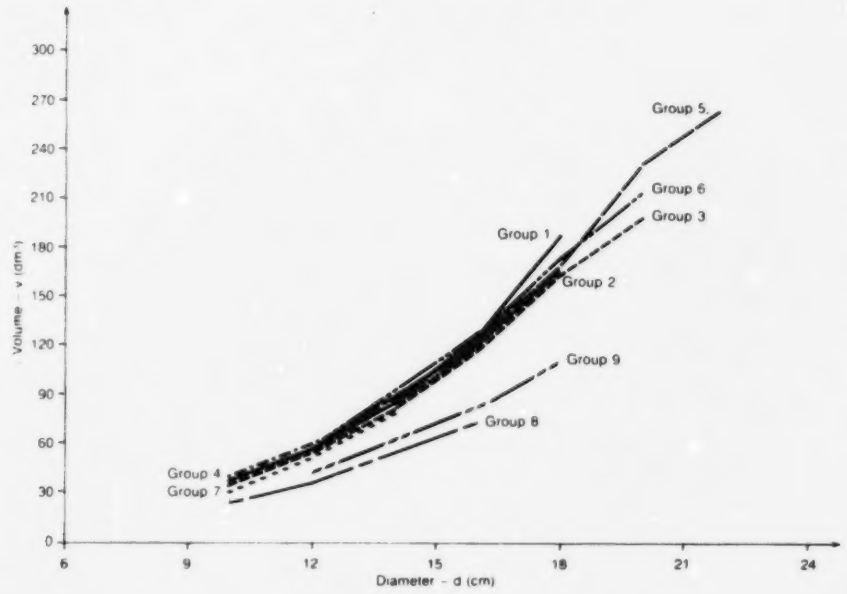

Figure 8. Tree volume (i.b.) in relation to dbh (i.b.) for nine groups of stands.

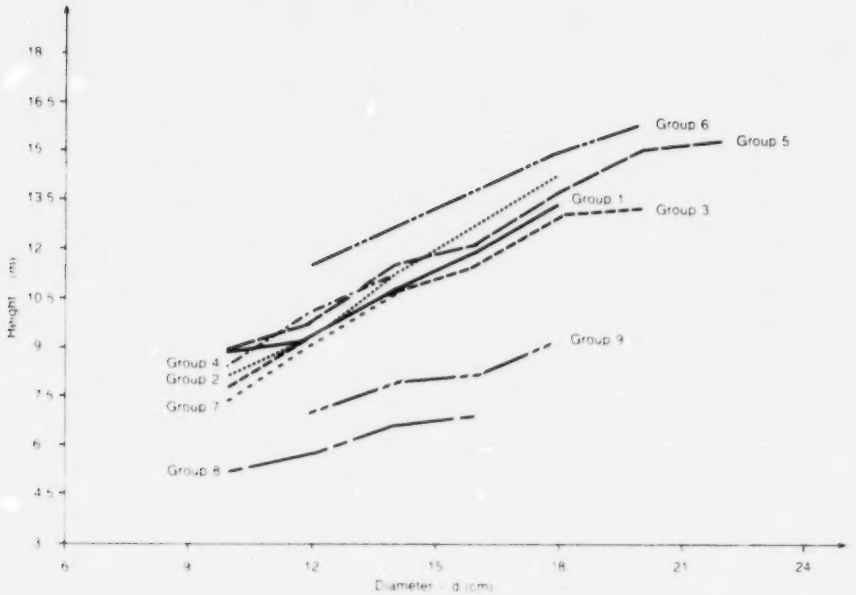

Figure 9. Tree height in relation to dbh (i.b.) for nine groups of stands.

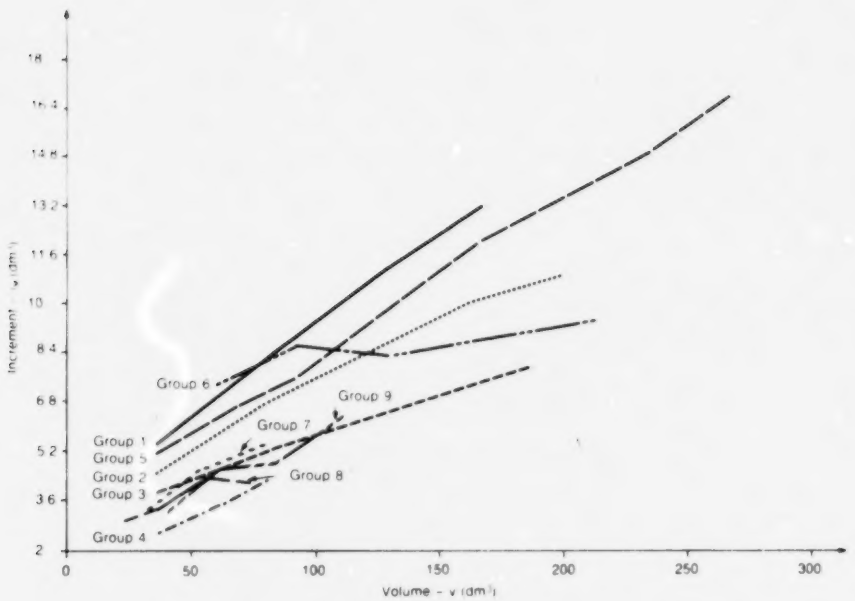

Figure 10. Tree annual volume increment (i.b.) in relation to the average tree volume (i.b.) for nine plot groups.

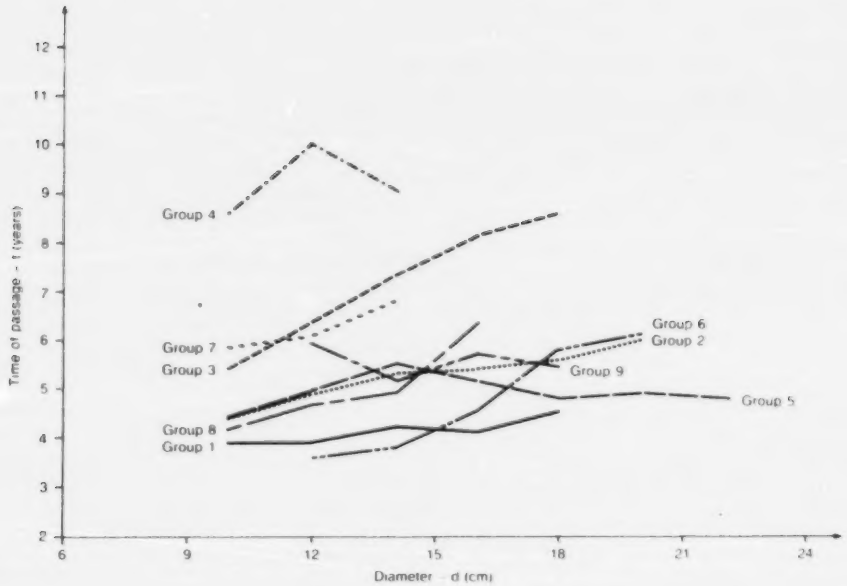

Figure 11. Time of passage in relation to the dbh for nine plot groups.

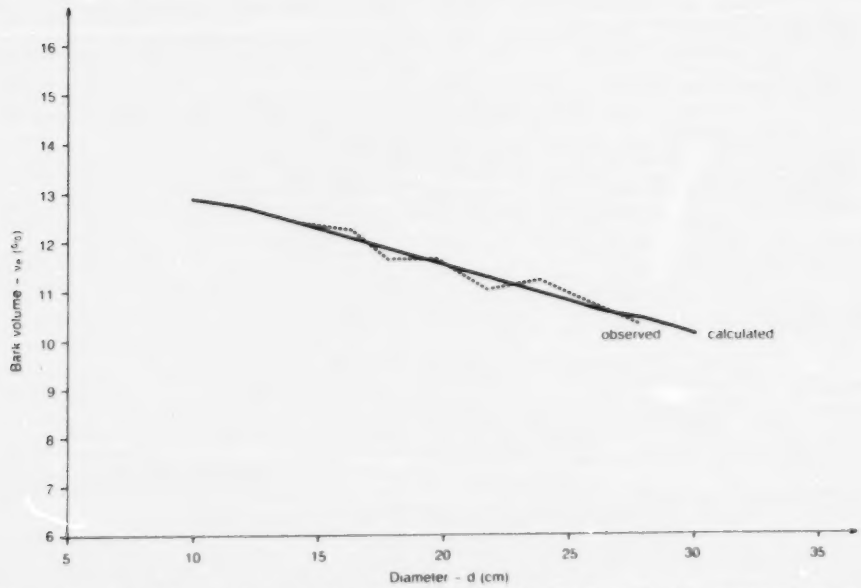

Figure 12. Bark volume (as a % of total tree volume) in relation to the dbh (o.b.) for balsam fir and white spruce.